Vaccine 41 (2023) 2932–2940

Contents lists available at ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

The effect of vaccine mandate announcements on vaccine uptake in Canada: An interrupted time series analysis

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ARTICLE INFO

Article history:
Received 28 November 2022
Received in revised form 17 March 2023
Accepted 21 March 2023
Available online 3 April 2023

Keywords:
Vaccine mandates
Vaccination coverage
Health intervention
Time series analysis

ABSTRACT

Introduction: In 2021, the ten provinces in Canada enacted COVID-19 vaccine mandates that restricted access to non-essential businesses and services to those that could provide proof of full vaccination to decrease the risk of transmission and provide an incentive for vaccination. This analysis aims to examine the effects of vaccine mandate announcements on vaccine uptake over time by age group and province.
Methods: Aggregated data from the Canadian COVID-19 Vaccination Coverage Surveillance System (CCVCSS) were used to measure vaccine uptake (defined as the weekly proportion of individuals who received at least one dose) among those 12 years and older following the announcement of vaccination requirements. We performed an interrupted time series analysis using a quasi-binomial autoregressive model adjusted for the weekly number of new COVID-19 cases, hospitalizations, and deaths to model the effect of mandate announcements on vaccine uptake. Additionally, counterfactuals were produced for each province and age group to estimate vaccine uptake without mandate implementation.
Results: The times series models demonstrated significant increases in vaccine uptake following mandate announcement in BC, AB, SK, MB, NS, and NL. No trends in the effect of mandate announcements were observed by age group. In AB and SK, counterfactual analysis showed that announcement were followed by 8 % and 7 % (310,890 and 71,711 people, respectively) increases in vaccination coverage over the following 10 weeks. In MB, NS, and NL, there was at least a 5 % (63,936, 44,054, and 29,814 people, respectively) increase in coverage. Lastly, BC announcements were followed by a 4 % (203,300 people) increase in coverage.
Conclusion: Vaccine mandate announcements could have increased vaccine uptake. However, it is difficult to interpret this effect within the larger epidemiological context. Effectiveness of the mandates can be affected by pre-existing levels of uptake, hesitancy, timing of announcements and local COVID-19 activity.

1. Introduction

Immunization against COVID-19 has been proven to be effective in reducing the spread and severity of the disease [1,2]. Widespread vaccination has also shown to be effective in reducing strain on the healthcare system and minimizing the economic burden of COVID-19 [3].

In Canada, COVID-19 vaccination began in December 2020, with the prioritization of specific populations; adults residing in remote and isolated Indigenous communities, healthcare workers and the elderly [4]. By the beginning of June 2021, with increased vaccine supply and emerging evidence on vaccine effectiveness, mixed vaccine schedules were approved, and vaccine eligibility had grown to include all individuals aged 12 and older [5,6]. These changes resulted in an initial rapid increase in vaccine uptake, from 70 % of 12-year-olds and over having received at least one dose in early June to 80 % by the end of July [7]. However, by August, uptake had slowed down, particularly amongst younger age groups [7]. Furthermore, the emergence of the Delta variant during the summer of 2021 showed to increase risk of transmission, hospitalization and death, compared to previous variants. This resulted in provincial and territorial governments reinstating non-pharmaceutical interventions such as capacity limits and masks [8].

In addition, starting in September 2021, provincial and territorial governments enacted mandates restricting access to non-essential businesses and services to those with proof of full vaccination or in some cases proof of a negative COVID-19 test (Alberta

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https://doi.org/10.1016/j.vaccine.2023.03.040
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and Saskatchewan). These mandates were aimed mostly at reducing viral transmission, but they were also expected to increase vaccine uptake. Mandates varied slightly across provinces with regards to the date of announcement, the time between announcement and implementation and mandate definitions. Table 1 provides a summary of the mandate announcement date, time between announcement and implementation and vaccination coverage prior to the announcement across provinces.

Vaccination requirements have been shown to increase vaccine uptake, as demonstrated by mandates for Measles and Rubella immunizations as well as Influenza vaccinations amongst healthcare workers [9,10]. However, there are variations in magnitude and speed of uptake due to preceding factors, often resulting in hesitancy or delay. Prior to the implementation of COVID-19 vaccine mandates across provinces, historically in Canada, vaccine mandates for the broader population have rarely been implemented as a measure to further mitigate the transmission of infectious diseases [11].

Other studies have looked at the effect of COVID-19 vaccine mandates on vaccine uptake and concluded that the announcement and implementation of COVID-19 vaccine mandates resulted in a sharp increase in uptake after the announcement followed by above average increase in subsequent weeks then a decline [12–15]. One study found a greater impact in younger age groups [14]. However, there are no peer reviewed studies assessing the effect by age group using Canadian data. Given the expanding age-based vaccine eligibility up to June 2021 in Canada, the proportion of those who were yet to receive a first COVID-19 vaccine dose varied across age groups at the time of the announcements. It is important to understand how vaccine mandates impacted these demographic groups and how varying vaccination coverage pre-mandate impacted uptake. Moreover, there exist no studies that used standardized data to calculate vaccine uptake. Existing literature relied on doses administered data from publicly available sources, rather than people vaccinated, which may not only include invalid doses and potential double reporting that may occur between reporting jurisdictions but also use different methods of inclusion criteria for doses administered [12,14]. Additionally, by using the proportion of people with at least one dose as a measure of vaccine uptake rather than counts of doses or people, the fitted models consider the notion that there is a limit to the number of people that can be vaccinated or doses that can be distributed in a population.

This interrupted time series analysis aimed to describe and measure the impact vaccine mandates announcements on COVID-19 vaccine uptake in Canadian provinces from July to November 2021 by age group.

2. Methods

2.1. Data sources

Aggregated weekly data on the number of individuals 12 years and older who received at least one dose were drawn from the Canadian COVID-19 Vaccination Coverage Surveillance System (CCVCSS) [7], and sourced from provincial and territorial immunization registries. The denominators used to calculate the vaccination rates in eligible individuals were population estimates as of July 1, 2021 provided by Statistics Canada, based on the 2016 Census of Population [16]. Aggregated COVID-19 weekly case, hospitalization and mortality data using the first Saturday following the episode date from July 2, 2021 to March 11, 2022, were obtained from the National COVID-19 Case dataset, which includes detailed case-level information received from all provinces and territories, maintained by the Public Health Agency of Canada (PHAC) [17].

2.2. Statistical analysis

The dependent variable was vaccine uptake, defined as the weekly proportion of individuals who received at least one dose. Vaccine mandate announcements by provincial governments were used as the reference date to measure the impact of the vaccination mandates over time (prior to and following the announcement date). An important assumption in time series analysis is stationarity in the outcome variable, or in this case, a homogenous mean and variance over time in weekly vaccine uptake. Periods of high vaccine uptake due to the expansion of vaccination eligibility and improving vaccine supply before July 2021 (Figure S1) could have violated this assumption and therefore limited the beginning date of our analysis. Our ending date was also limited due to the emergence of the omicron variant in late November 2021 (Figure S2), which could have also impacted the stationarity of vaccine uptake over time. As a result, vaccination coverage data from a 16-week interval between July and November was used to measure vaccination coverage and vaccine uptake; the period from 5 weeks prior to 10 weeks after the week of vaccine mandate announcement in each province. Exact timelines used for analysis in each province is illustrated in Table 1. Based on data availability and mandate implementation during this period, the ten provinces were included in the analysis: British Columbia (BC), Alberta (AB), Saskatchewan (SK), Manitoba (MB), Ontario (ON), Quebec (QC), New Brunswick (NB), Nova Scotia (NS), Prince Edward Island (PE), and Newfoundland and Labrador (NL). The three territories (Yukon,

Table 1
COVID-19 vaccine mandate and vaccination coverage characteristics by province.

Province	Population	Study Period		Announcement date	Weeks between announcement and implementation	Vaccination coverage during the week prior to announcement in those 12 years and older
		Start	End			
BC	4,633,749	24/07/2021	06/11/2021	23/08/2021	3 weeks	82.50 %
AB	3,791,830	14/08/2021	27/11/2021	15/09/2021	<1 week	76.87 %
SK	996,896	31/07/2021	13/11/2021	30/08/2021	5 weeks	76.96 %
MB	1,176,028	24/07/2021	06/11/2021	27/08/2021	1 week	83.06 %
ON	13,038,032	31/07/2021	13/11/2021	01/09/2021	3 weeks	82.63 %
QC	7,532,471	03/07/2021	16/10/2021	05/08/2021	4 weeks	82.84 %
NB	701,879	14/08/2021	11/27/2021	15/09/2021	1 week	84.05 %
NS	884,353	07/08/2021	20/11/2021	08/09/2021	4 weeks	85.80 %
PE	145,431	21/08/2021	04/12/2021	21/09/2021	3 weeks	89.66 %
NL	467,760	14/08/2021	27/11/2021	17/09/2021	5 weeks	89.77 %

BC - British Columbia, AB - Alberta, SK - Saskatchewan, MB - Manitoba, ON - Ontario, QC - Quebec, NB - New Brunswick, NS - Nova Scotia, PE - Prince Edward Island, NL - Newfoundland and Labrador

Northwest Territories and Nunavut) were not included in the analysis since they did not implement any public COVID-19 vaccine mandates during the period included for analysis.

2.3. Descriptive analysis

The cumulative proportion of the population aged 12 years and older who had received at least one dose of a COVID-19 vaccine (i.e. vaccination coverage) was computed to describe vaccination rates across province and age group prior to and following the mandate announcement date. The weekly proportion of individuals who received at least one dose (i.e. vaccine uptake) was used to describe the change in vaccination coverage over time across demographic variables (Figure S1). A descriptive analysis of the weekly proportion of individuals who completed their primary series was also conducted. However, the impact of vaccine mandate announcements on vaccine uptake among individuals who completed their primary series was not assessed statistically since uptake among these individuals seem to remain stable during the period where vaccine mandates were announced and implemented (Figure S3).

2.4. Model

The following quasi-binomial autoregressive (AR) model was applied to examine the effects of vaccine mandate announcement on vaccine uptake over time by age group and province

$$\mathrm{Log}(V_{ijt}) = c_{ijt} + \tau T_{jt} + \pi_1 P_{jt} + \pi_2 (T_{jt} - T_{jt=x-1}) P_{jt} + \lambda_1 V_{ijt-1} + \lambda_2 V_{ijt-2} + \mu_1 C_{ijt} + \mu_2 H_{ijt} + \mu_3 M_{ijt} + \varepsilon_{ijt}$$

V_{ijt} is the weekly proportion of individuals who received at least one dose among the age group i, in province j, during week t

c_{ijt} is a constant.

T_{jt} is a linear time variable (in weeks) initialized at t = 0 and increases by 1.

P_{jt} is an interrupted time series effect variable set to 0 for weeks prior to mandate announcement and 1 during the week of announcement and onwards. The corresponding coefficient, π_1, indicates the level shift in uptake due to the mandate announcement.

$(T_{jt} - T_{jt=x-1})P_{jt}$ is an interrupted time series effect variable set to 0 during the weeks prior to the mandate announcement and increases by 1 during and after the week of mandate announcement ($T_{jt=x-1}$ is the time, in weeks, since the week prior to mandate announcement), x is the time elapsed since the week of mandate announcement. The corresponding coefficient, π_2, indicates the slope change in uptake during the weeks following the mandate announcement.

λ_1 and λ_2 indicate the magnitude of autocorrelation to the 1 week and 2 week lagged values of V_{ijt}, respectively.

C_{ijt} indicates the weekly number of cases per 100,000 population of COVID-19 infection.

H_{ijt} indicates the weekly number of hospitalizations per 100,000 population due to COVID-19 infection.

M_{ijt} indicates the weekly number of deaths per 100,000 population due to COVID-19 infection.

Cases (C_{ijt}), hospitalizations (H_{ijt}) and death (M_{ijt}) counts were included to adjust for their potential effects on vaccine uptake. Specifically, case, hospitalization, and mortality counts may increase vaccination rates since more cases may motivate individuals to get vaccinated, however it may also decrease vaccination rates since infected individuals are not able to get vaccinated.

2.5. Counterfactuals

Counterfactual analysis looks to quantify the outcomes (vaccine uptake) of an intervention (announcement of vaccine mandate) compared to the outcomes that would have been achieved if said intervention was not implemented [18–19]. Counterfactuals were computed by setting the model coefficients of the level shift (π_1) and the slope change (π_2) effects of the vaccine mandate to zero along with an iterative process to account for the autoregressive components of the model [12,18,20]. Significance was determined at a 5 % alpha level.

3. Results

Across Canadian provinces, vaccine mandates for public gatherings were announced between August 5 (in QC) and September 21 (PE) [21–30]. During the week prior to announcing their vaccine mandates, vaccination coverage ranged between 76.87 % (AB) and 89.77 % (NL) in the provinces (Table 1). Among age groups, vaccination coverage increased with increasing age groups; the lowest coverage was observed among those 12–29 years old in AB, SK, and MB and the highest among those 60 years or older in MB and PE. Weekly vaccine uptake varied across the provinces over time (Figure S1). Some provinces like AB and SK demonstrated sharp increases in uptake following mandate announcements, while others (MB, ON, QC) showed a slight increase (<0.01 percentage point, p.p.) in the first week of announcement followed by a steady decrease overtime. Conversely, over the analysis period, there were slight increases in weekly number of COVID-19 cases in BC, AB, SK, ON, and QC, while it remained relatively low and stable in PE and NL up to 12 weeks after mandate announcement dates (Figure S2).

From the interrupted time series models, we found a significant association between the level shift effects of vaccine mandates and increased vaccine uptake in BC, AB, MB, NS, and NL for those 12 years and older (Table 2). By far, we see the largest level shift effect in AB (p = <0.001), which had one of the lowest levels of vaccination coverage among the provinces prior to the announcement. When stratified by age group, the impact of level shift effects varied across the provinces. In BC, the impact was significant across all age groups except amongst those 70 years old or over. In AB, level shift effects were significant regardless of age. In MB, significance was only observed in adults between 18 and 69 years old. In NS, significant estimates were only observed in the 40–49 age group. Lastly, in NL, the impact was significant in youths 12–17 years old and in adults between 40 and 59 years old. Overall, while the level shift impact of the vaccine mandates was significant in some age groups, no age-specific trends were observed across the provinces.

For slope change effects of the vaccine mandate, associations to increased vaccine uptake among 12 years and older were found in SK and MB (Table 3). By age strata, slope change effects were significant among individuals 12–17 and 40–59 years old in SK and age groups 18–29, 40–59, and 70 + in MB. Lastly, slope change effects were associated with *decreased* vaccine uptake overall in PE and among some age groups in ON, NS, and NL.

Estimates for the control variables (T_{jt}, C_{ijt}, H_{ijt}, and M_{ijt}) are illustrated in Table S1 and model *R*-squared values are illustrated in Table S2. Note that certain age groups and provinces, especially those 12–17 years old or those residing in PE, did not have episodes of COVID-19 hospitalization or deaths during the 16-week study period, therefore we could not control for them in the models. Overall, T_{jt} and C_{ijt} were significant in only some age groups and

Table 2
Level shift effects (π_1) of vaccine mandate announcement by province and age group in the ten Canadian provinces/territories (PT) within a 16-week study period from July to November 2021.

PT	Age group								All eligible population (12 +)
	12–17	**18–29**	**30–39**	**40–49**	**50–59**	**60–69**	**70–79**	**80+**	
	π_1 (95 % CI) p-value	π_1 (95 % CI) p-value	π_1 (95 % CI) p-value	π_1 (95 % CI) p-value	π_1 (95 % CI) p-value	π_1 (95 % CI) p-value	π_1 (95 % CI) p-value	π_1 (95 % CI) p-value	π_1 (95 % CI) p-value
BC	**1.8 (1.3–2.4)** **0.000**	**2.4 (1.6–3.6)** **0.002**	**2.1 (1.2–3.7)** **0.008**	**2.0 (1.6–2.5)** **0.003**	**1.6 (1.0–2.4)** **0.047**	**2.9 (1.2–7.2)** **0.009**	1.8 (0.7–4.8) 0.108	1.3 (1.0–1.7) 0.139	**2.0 (1.0–3.8)** **0.020**
AB	**3.8 (2.3–6.3)** **<0.001**	**8.6 (5.8–12.6)** **<0.001**	**3.1 (2.6–3.7)** **<0.001**	**4.5 (4.1–4.9)** **<0.001**	**3.6 (3.5–3.7)** **<0.001**	**3.6 (3.3–3.9)** **<0.001**	**3.1 (1.9–4.9)** **0.001**	**4.4 (1.0–19.7)** **0.027**	**4.2 (3.6–5.0)** **<0.001**
SK	0.6 (0.3–1.2) 0.074	0.6 (0.1–2.7) 0.375	0.6 (0.1–2.3) 0.277	0.5 (0.2–1.4) 0.085	0.6 (0.1–3.3) 0.478	0.9 (0.5–1.4) 0.435	0.8 (0.2–3.1) 0.632	1.2 (0.4–3.4) 0.593	0.5 (0.2–1.3) 0.063
MB	1.7 (0.3–8.7) 0.409	**3.5 (1.1–10.6)** **0.011**	**2.1 (1.1–4.2)** **0.016**	**2.2 (1.0–4.8)** **0.022**	**2.2 (1.2–3.9)** **0.008**	**2.2 (1.6–3.1)** **0.002**	**1.5 (1.3–1.7)** **0.025**	1.3 (0.8–2.0) 0.222	**2.4 (1.3–4.3)** **0.005**
ON	1.5 (0.9–2.3) 0.084	1.5 (0.8–2.8) 0.103	1.3 (0.8–2.3) 0.177	1.0 (0.7–1.5) 0.948	1.2 (0.6–2.5) 0.382	1.4 (0.8–2.3) 0.146	1.4 (0.7–3.0) 0.205	1.4 (1.1–1.6) 0.068	1.2 (0.6–2.4) 0.380
QC	0.9 (0.3–2.5) 0.648	0.7 (0.4–1.5) 0.237	1.1 (1.0–1.1) 0.676	1.0 (0.7–1.5) 0.784	1.2 (1.1–1.4) 0.148	1.1 (0.8–1.6) 0.501	0.9 (0.5–1.9) 0.802	0.8 (0.2–2.9) 0.643	0.8 (0.5–1.3) 0.348
NB	0.6 (0.1–6.1) 0.692	1.3 (0.2–10.4) 0.806	2.3 (0.5–11.4) 0.201	1.5 (0.3–9.2) 0.554	1.4 (0.2–8.8) 0.632	9.0 (0.9–89.4) 0.106	3.2 (0.4–22.8) 0.222	1.9 (0.3–13.9) 0.465	1.5 (0.2–12.4) 0.678
NS	**1.9 (0.9–4.1)** **0.035**	2.7 (0.7–9.9) 0.058	2.2 (0.5–10.6) 0.186	**4.7 (1.0–21.6)** **0.022**	3.4 (0.7–17.9) 0.088	2.3 (0.4–11.6) 0.228	1.6 (0.3–8.0) 0.415	1.4 (0.6–3.3) 0.215	**4.2 (1.2–14.2)** **0.009**
PE	1.5 (0.3–8.3) 0.559	1.5 (0.5–4.0) 0.261	1.6 (0.6–4.7) 0.187	2.5 (0.7–9.2) 0.070	2.4 (0.6–9.8) 0.092	2.5 (0.4–17.2) 0.288	11.3 (1.3–102.1) 0.049	17.4 (0.1–2149.9) 0.850	1.7 (0.7–3.8) 0.101
NL	**3.8 (0.8–19.1)** **0.049**	1.1 (0.4–3.3) 0.808	2.0 (0.7–6.0) 0.095	**6.6 (1.4–30.3)** **0.009**	**4.6 (1.1–19.8)** **0.020**	0.9 (0.1–5.6) 0.863	6.1 (0.6–59.9) 0.162	2.5 (0.2–30.5) 0.562	**3.6 (0.9–14.0)** **0.026**

Boldface values indicate estimates that are significant at 5 % alpha level.

Table 3
Slope change effects (π_2) of vaccine mandate announcement by province and age group in the ten Canadian provinces/territories (PT) within a 16-week study period from July to November 2021.

PT	Age group								All eligible population (12 +)
	12–17	**18–29**	**30–39**	**40–49**	**50–59**	**60–69**	**70–79**	**80+**	
	π_2 (95 % CI) p-value	π_2 (95 % CI) p-value	π2 (95 % CI) p-value	π_2 (95 % CI) p-value	π_2 (95 % CI) p-value	π_2 (95 % CI) p-value	π_2 (95 % CI) p-value	π_2 (95 % CI) p-value	π_2 (95 % CI) p-value
BC	1.1 (0.5–2.4) 0.125	0.8 (0.6–0.9) 0.091	1.1 (0.3–3.9) 0.820	1.2 (0.9–1.6) 0.076	1.4 (0.9–2.1) 0.108	0.7 (0.5–1.1) 0.108	0.9 (0.7–1.0) 0.353	1.0 (0.5–2.2) 0.983	0.9 (0.2–3.4) 0.753
AB	1.2 (1.0–1.6) 0.214	1.1 (0.9–1.4) 0.310	1.1 (0.9–1.3) 0.395	1.1 (1.0–1.2) 0.428	1.2 (1.0–1.4) 0.133	1.1 (0.8–1.5) 0.537	1.1 (0.8–1.3) 0.742	1.1 (0.7–2.0) 0.567	1.3 (1.0–1.6) 0.131
SK	**1.2 (0.8–1.9)** **0.036**	1.5 (0.8–2.8) 0.124	1.6 (0.8–3.1) 0.098	**1.5 (1.4–1.6)** **0.019**	**1.7 (0.9–3.2)** **0.044**	1.2 (1.0–1.5) 0.056	1.2 (0.9–1.5) 0.341	1.1 (0.7–1.6) 0.354	**1.5 (1.4–1.7)** **0.005**
MB	1.6 (0.9–2.8) 0.062	**1.4 (1.2–1.6)** **0.043**	1.1 (1.0–1.3) 0.311	**1.4 (1.3–1.4)** **0.044**	**1.4 (1.2–1.6)** **0.015**	1.2 (0.9–1.5) 0.339	**2.0 (1.8–2.1)** **0.001**	**2.2 (1.2–3.9)** **0.008**	**1.4 (1.3–1.5)** **0.024**
ON	1.1 (0.9–1.3) 0.533	0.9 (0.7–1.1) 0.397	0.9 (0.8–0.9) 0.243	**0.8 (0.5–1.2)** **0.030**	0.8 (0.7–0.8) 0.052	0.9 (0.8–1.0) 0.365	1.1 (1.0–1.3) 0.388	1.0 (0.5–2.0) 0.517	0.8 (0.6–1.0) 0.150
QC	0.9 (0.6–1.3) 0.259	1.1 (0.6–2.2) 0.065	1.0 (0.3–3.3) 0.560	1.0 (0.4–2.1) 0.371	1.0 (0.3–3.6) 0.373	1.0 (0.6–1.7) 0.869	1.0 (0.7–1.2) 0.645	1.1 (0.4–3.1) 0.864	1.1 (0.5–2.2) 0.312
NB	0.9 (0.5–1.7) 0.591	0.7 (0.5–1.1) 0.137	0.7 (0.7–0.8) 0.052	0.8 (0.6–1.0) 0.164	0.8 (0.6–1.1) 0.271	1.0 (0.5–1.9) 0.914	0.9 (0.7–1.2) 0.581	0.9 (0.5–1.9) 0.812	0.8 (0.5–1.3) 0.282
NS	**0.7 (0.6–1.0)** **0.012**	0.9 (0.9–1.0) 0.486	1.0 (0.7–1.4) 0.884	1.1 (0.9–1.2) 0.704	1.3 (0.8–2.0) 0.201	1.2 (0.8–1.8) 0.310	1.4 (1.2–1.6) 0.056	**2.2 (1.8–2.7)** **0.000**	1.0 (0.9–1.1) 0.994
PE	0.9 (0.5–1.5) 0.648	0.8 (0.8–0.9) 0.131	0.8 (0.6–1.0) 0.067	0.8 (0.8–0.8) 0.108	1.0 (0.8–1.3) 0.979	0.7 (0.3–1.8) 0.332	1.1 (0.4–3.5) 0.761	1.0 (0.0–45.4) 0.997	**0.8 (0.5–1.5)** **0.034**
NL	1.2 (0.7–2.0) 0.358	**0.6 (0.5–0.9)** **0.024**	0.9 (0.9–0.9) 0.307	0.9 (0.8–1.0) 0.321	0.8 (0.6–1.2) 0.256	**0.6 (0.3–1.0)** **0.029**	1.1 (0.2–5.0) 0.867	0.5 (0.1–3.8) 0.462	0.9 (0.7–1.3) 0.707

Boldface values indicate estimates that are significant at 5 % alpha level.

provinces, particularly in the Prairie region (AB, SK, MB). H_{ijt} and M_{ijt} were not significant in almost all models. Lastly, the *R*-squared values were above 0.8 for most models except in models fitted for specific age groups in the Atlantic region (NB, NS, PE, and NL).

Results from the counterfactuals showed that the effects of the mandate could have lasted up to ten weeks after the vaccine mandate announcement in most provinces (Fig. 1). In BC, vaccine mandate announcement was followed by a 4.4p.p. (95 % CI 2.1–6.6) increase in vaccination coverage 10 weeks after the week of announcement date, which translates to 203,300 (98,253–308,346) more individuals 12 years old and over being vaccinated (Fig. 2). In AB, there was an 8.2p.p. (95 % CI 7.0–9.4) increase in coverage or 310,890 (267,169–354,611) additional people receiving at least one dose. In SK, a similar increase was observed (7.2p.p., 95 % CI 5.3–9.1) with 71,711 (52,337–91,084) more individuals being vaccinated. MB showed a 5.4p.p. (95 % CI 4.0–6.9) increase in coverage rates or 63,936 (46,841–81,030) more people being vaccinated. In NS, there was a 5.2p.p. (95 % CI 1.6–8.8) increase or 44,054 (14,052–78,056) more people being vaccinated. Lastly, in

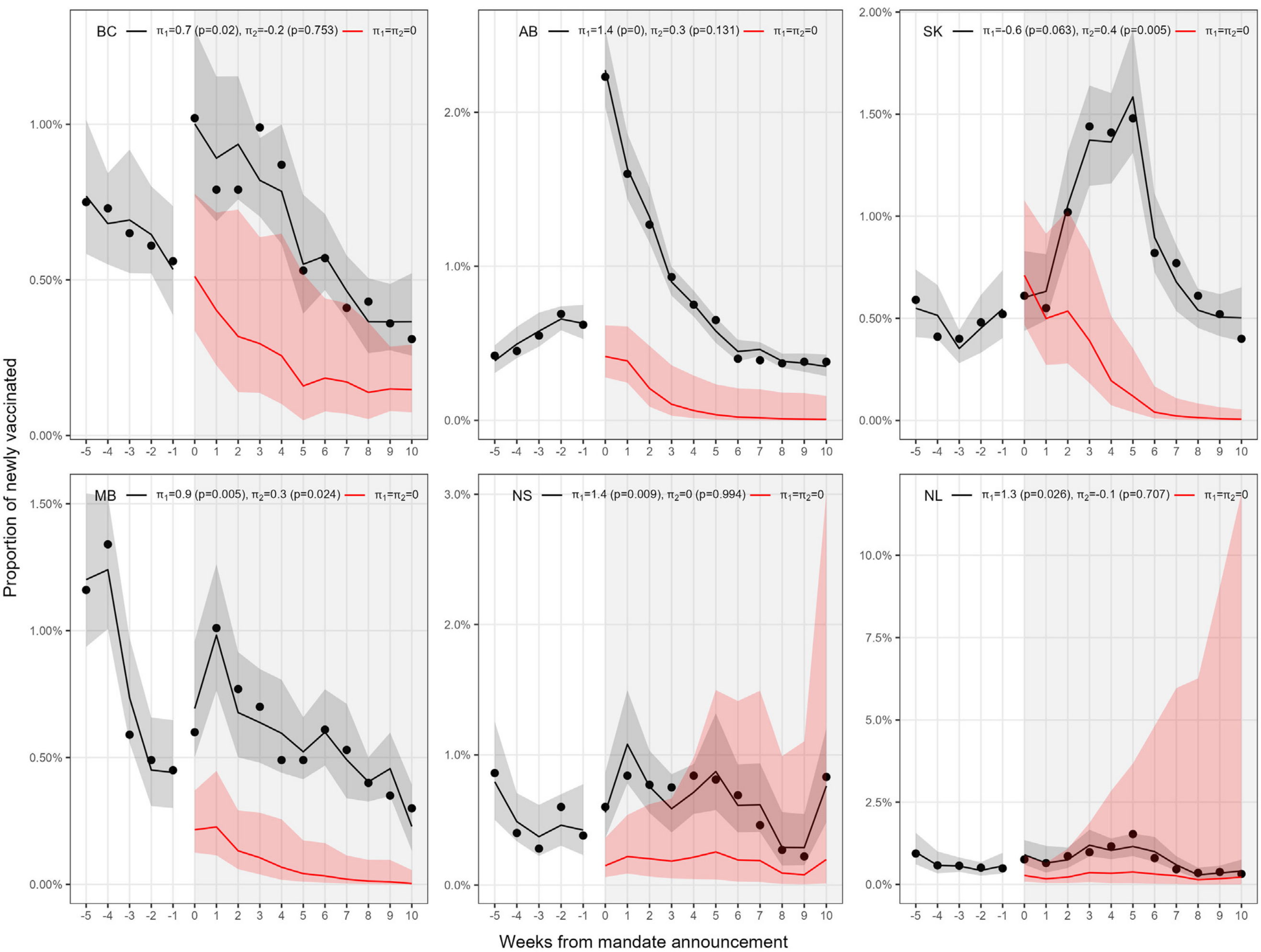

Fig. 1. Observed (black points) and estimated (black line) weekly vaccine uptake among 12 years and older in six provinces: British Columbia (BC), Alberta (AB), Saskatchewan (SK), Manitoba (MB), Nova Scotia (NS), and Newfoundland and Labrador (NL). Counterfactuals (in red) represent the removal of the level shift (π_1) and slope change (π_2) effects of vaccine mandates.

NL, vaccine mandate was associated with a 6.4p.p. (95 % CI 3.8–9.0) increase in coverage, or 29,814 (17,542–42,086) additional individuals being vaccinated.

3.1. Sensitivity analysis

Several sensitivity analyses were carried out among the eligible population to examine the robustness of the models. First, the same models were applied to investigate the impact of vaccine mandate implementation rather than mandate announcement and the results showed no significant level shift effect in most provinces, while the slope change effect was only negatively associated with vaccine uptake (Table S3). This suggests that uptake may have already started to decrease by the time mandates were implemented in most provinces and that the mandate announcements rather than implementations were more associated with increased uptake. Second, the analysis period was extended from 16 to 25 weeks (or 9 weeks pre-announcement and 15 weeks post-announcement) and findings remained significant except in SK (data not shown). Lastly, a different age group breakdown was used to assess the impacts of vaccine mandate announcements among adult non-seniors (18–59 years old) compared to seniors (60 years and older). Results from this sensitivity analysis showed that impacts of vaccine mandate announcements were more significant among non-seniors compared to seniors (Table S4).

4. Discussion

Overall, vaccine mandate announcements were followed by an increase in COVID-19 vaccine uptake in certain Canadian provinces. Studies in Canada and other countries have also demonstrated the positive effect of mandatory vaccination certificates on population vaccination rates [12–15,31]. We observed a significant impact of vaccine mandates in BC, AB, SK, MB, NS, and NL up to 10 weeks after vaccine mandate announcements. Level shift effects were observed in BC, AB, NS, and NL, and slope change effects were observed in SK. MB was the only province where both level shift and slope change effects were significant.

Vaccination coverage prior to mandate announcement can play a role on the extent of the impact of vaccine mandates. Presumably, a vaccine mandate would not be as effective in regions with high vaccination coverage compared to regions with low coverage. Indeed, AB and SK which had noticeably lower coverage rates prior to mandate announcements compared to the other provinces also returned the greatest increase in vaccination coverage percentage points. Similarly, a study in Europe found that countries with uptake that were below average prior to implementing mandatory COVID-19 certificates showed a greater increase in daily vaccinations compared with those where uptake was higher [14]. Interval between announcement and implementation dates may also contribute to the duration and degree of increased vaccine uptake

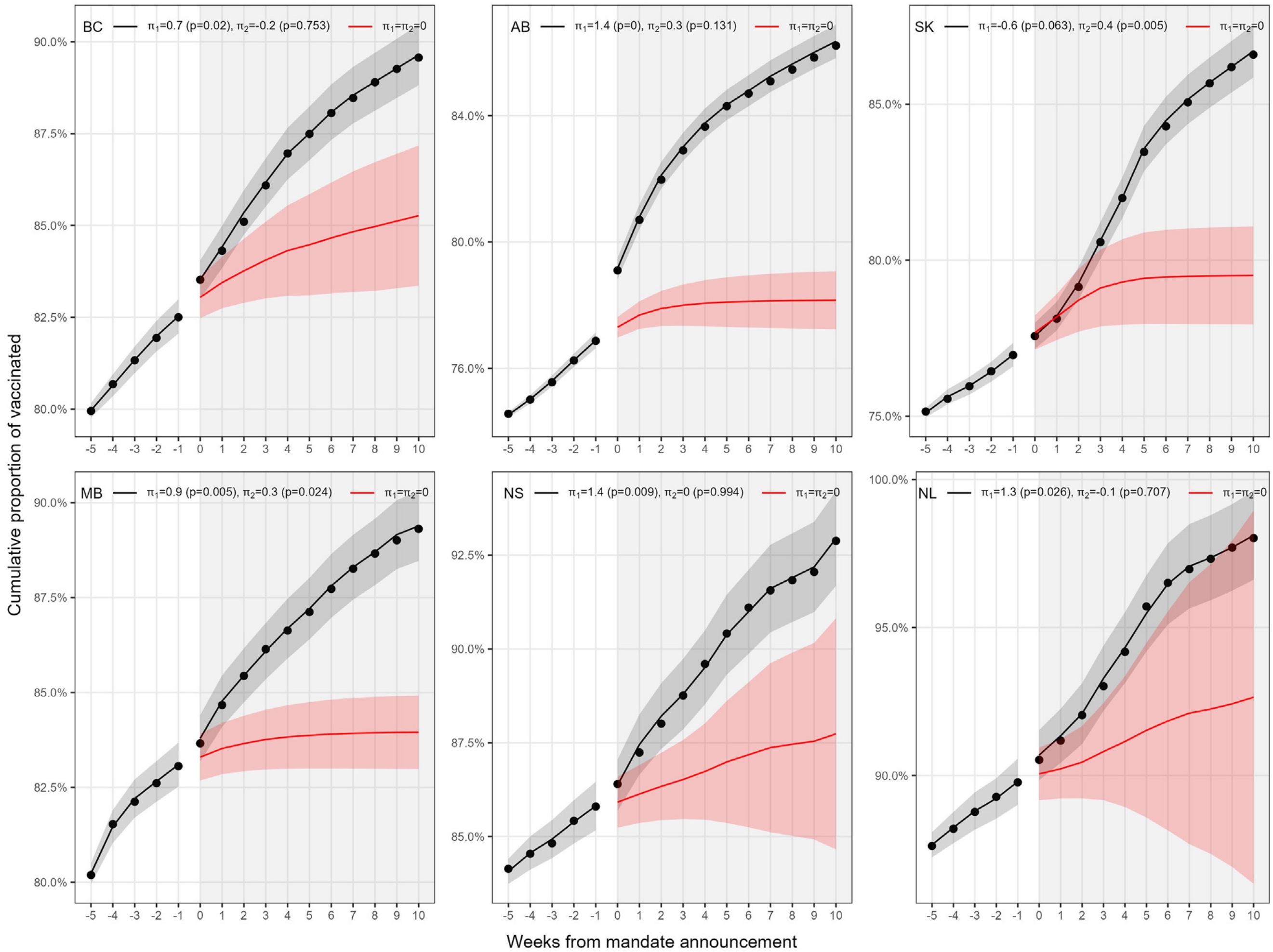

Fig. 2. Observed (black points) and estimated (black line) vaccination coverage among 12 years and older in six provinces: British Columbia (BC), Alberta (AB), Saskatchewan (SK), Manitoba (MB), Nova Scotia (NS), and Newfoundland and Labrador (NL). Counterfactuals (in red) represent the removal of the level shift (π_1) and slope change (π_2) effects of vaccine mandates.

attributable to mandates. SK and AB had the lowest coverage among all provinces. However, the level shift effect was significant in AB, but the slope change effect was not. In contrast, there was no level shift effect of the vaccine mandate in SK; instead, the slope change effect was significant (Fig. 1). AB announced vaccine mandates<1 week before it was implemented while SK made the announcement 5 weeks prior to implementation. The shorter window of time between mandate announcement and implementation in AB could have created more urgency for residents to get vaccinated leading to the steep immediate increase in uptake following the announcement. In contrast, SK residents had a greater window of time to get vaccinated before mandates were to be implemented, resulting in a slow increase in uptake leading up to the implementation date. Previous studies that explored the effect of COVID-19 vaccination mandate on vaccine uptake in Canadian provinces and internationally noted that along with a greater number of unvaccinated eligible population, shorter time between announcement and implementation may have contributed to a larger increase in uptake [12,13].

Provinces in the Atlantic region (NS, PE, and NL) exhibited negative slope change effects in some age groups (Table 3), suggesting that vaccine mandate announcements were followed by a *decrease* in vaccine uptake. Since these provinces were the last among all the others to announce a vaccine mandate, residents may have chosen to get vaccinated much earlier in anticipation of an announcement. Additionally, these provinces also had the highest coverage of vaccination prior to announcing mandates (Table 1). Considering these two factors, uptake may have already started to slow down by the time the Atlantic provinces made the announcements leading to a negative effect. Negative effects can also be associated with increased hesitancy to get vaccinated among unvaccinated individuals. Previous studies in Canada, USA, and UK have shown that enforcing vaccination passports to limit access to non-essential businesses and services could lead to decreased willingness to get vaccinated [32–35], which is contrary to a study in Quebec showing that the implementation of COVID-19 passports had a positive effect on willingness to receive COVID-19 doses [34].

No significant level shift or slope change effects were observed in both Ontario and Quebec for the eligible population, postulating that the vaccine mandate announcements were not followed by an increase in vaccine uptake. A similar study also showed no effect in Quebec and a significant but small effect in Ontario [12]. Since these are the largest provinces in Canada making up more than 60 % of the Canadian population, there is the potential that other mandates targeting subpopulations within the province during the period of interest could have dampened the effect of the provincial wide mandate. For instance, many large institutions like local government and universities mandated proof of vaccination in and around the same period as the announcement of the provincial mandate. Other informal announcements before the official one, as was the case in Quebec, may have contributed to an early spur in uptake resulting in a more steady increase in vaccine uptake spread over time before the actual mandate announcement date [36]. This would have reduced the ability of an analysis like this one, based on official announcements, to detect an effect of vaccine mandates.

Some studies have shown that the impact of implementing COVID-19 certificates were greater among the younger adult population [13,14,31]. While a greater impact among younger age groups was expected since these groups had lower coverage rates prior to mandate announcements compared to older groups largely due to vaccine eligibility policies, trends were inconsistent when data was stratified by age group between provinces. This may be due to the differences in the quality of our data across age groups and provinces, leading to inconsistent results. A sensitivity analysis with fewer age groups showed that the impact of vaccine mandate announcement was generally more associated with increased uptake among adult non-seniors (i.e., those 18–59 years old) compared to seniors (60 years or older) (Table S4). Another explanation for the lack of effects among younger age groups in some provinces may be related to age differences in vaccine hesitancy. A recent study suggested that mandatory vaccine certificates were unlikely to affect vaccination intentions particularly among those aged 18–24 years [32]. Therefore, considering the potentially conflicting effects of coverage and vaccination hesitancy rates are crucial in order to better understand the impact of vaccine mandates on uptake among specific age groups.

Additional research is needed to better understand the effect of different types of mandates on different sections of the population. For instance, the potential effects of municipal or employee mandates on local coverage and target populations. Studies in the USA have shown that employment mandates are generally more accepted in the population and are more likely to address vaccination hesitancy compared government mandates [37,38]. Additionally, a study in Hawaii showed that business mandates were associated with an 8 % increase in vaccination rates among employers [39]. Given that we did not account for these factors, our findings may overestimate the impact of provincial vaccine mandate announcements on vaccination coverage or vaccine uptake in regions where municipal and/or employment mandates were implemented during or around the same time as the studied vaccine mandate announcements. Additional research will also be needed to evaluate the economic evaluations of mandate rollouts, and effects of mandates on intention to get vaccinated and individuals' knowledge, attitudes and beliefs towards vaccination in general, particularly in the Canadian setting.

4.1. Strengths

This analysis contributes to the body of evidence on the impact of a public health intervention on vaccine uptake and vaccination coverage, and used data sourced directly from the provinces immunization registry [12]. Using data on people vaccinated based on standardized definitions of vaccination status across Canadian provinces reduces the potential risk of invalid doses inflating the true magnitude of the effect of vaccine mandate announcements on vaccine uptake. Furthermore, this analysis explored vaccine uptake by age, which allowed us to account for the pre-mandate vaccination coverage level given the vaccine roll out eligibility was based on age. This study also considers the level shift and slope change effects of announcing vaccine mandates and provides insight on why these effects may differ by province and age population. Our findings suggest that the level shift and slope change effects of vaccine mandate vary across provinces and age groups therefore different impact models may be warranted to accurately measure the impacts of vaccine mandates on vaccine uptake in Canada [18,20].

5. Study limitations

Although effects were not observed across all provinces and among all age groups, the mandates may still have contributed to increased uptake. Lack of significance does not necessarily mean that the vaccine mandates did not have a positive impact. Due to the high variability in weekly vaccine uptake and the limited number of weeks included in the analysis, the data may not have had enough statistical power to detect any differences.

With the data being aggregated at the provincial level, the analysis is unable to distinguish the potential effect of other mandates such as those enforced by workplaces or institutions. These mandates applied on a smaller scale could have influenced individual behaviours and beliefs regarding COVID-19 vaccination.

An important assumption in time series analysis is stationarity in the outcome variable, or in this case, a homogenous mean and variance over time in weekly vaccine uptake. In interrupted time series analysis, a formal test for this assumption requires sufficient observations prior to the health intervention (i.e., the vaccine mandate announcement) which was not available in our data [19]. Therefore, to attenuate the impact of potential non-stationarity, we explicitly included weeks when vaccine uptake was presumably stationary. A sensitivity analysis showed that results remained consistent in all provinces except for SK when extending the study period from 16 to 25 weeks.

Other factors which may have contributed to the increase in vaccine uptake could not be accounted in the analysis, such as social factors (back-to-school period), increased in vaccine supply and changes to provincial or NACI recommendations on vaccination programs during the period of interest.

Lastly, demographic and socioeconomic characteristics known to be associated with vaccine uptake, such as race or ethnicity, level of education and income, were not available in provincial immunization registries [40–44]. Further studies are needed to investigate the effect of vaccine mandates on vaccine uptake in sub-population groups across socioeconomic strata.

6. Conclusion

We can conclude that vaccine mandate announcements in certain jurisdictions were followed by an increase in COVID-19 vaccine uptake from July to November 2021, when compared to the absence of vaccine mandate announcements. This analysis highlights the relevance of using immunization registry data for the purpose of maintaining public health surveillance and examining the impact of public health interventions on vaccination coverage. Although other factors may have influenced the magnitude and duration of increased vaccine uptake, this paper contributes to the growing evidence of the positive effects of mandatory COVID-19 vaccination on vaccine uptake in the context of increasing vaccination coverage to reduce ongoing community disease transmission and the emergence of new variants. Lastly, understanding how vaccination requirements affects vaccine uptake across socioeconomic strata is important to inform implications for future vaccination policy.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors thank provincial and territorial partners who provided the data for their continued collaboration. We also thank the team members of the Vaccination Coverage and Immunization Surveillance of the Vaccine Roll-Out Task Force branch at the Public Health Agency of Canada (PHAC) for their contribution in data collection and processing, as well as in synthesizing the environmental scan with regards to the timeline for provincial and territorial vaccine mandate dates. The authors would also like to thank the Data Integration Team and the COVID-19 Surveillance Team of the Centre for Immunization and Respiratory Infectious Diseases at the PHAC, for providing the national COVID-19 case dataset.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2023.03.040.

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